(NASA-CR-196075) SOME ASPECTS OF SIMULTANEOUSLY FLYING TOPEX FOLLOW-ON IN A TOPEX ORBIT WITH GEOSAT FOLLOW-ON IN A GEOSAT ORBIT Final Report (Colorado Univ.) 10 p

N94-34214

Unclas

G3/43 0009438

NASA-CR-196075

FINAL REPORT -- NAG-1-1506
University of Colorado
Boulder, CO 80309

FINAL
IN-43-CR
9438
P. 10

Some Aspects of Simultaneously Flying Topex Follow-On in a Topex Orbit with Geosat Follow-On in a Geosat Orbit

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May 4, 1994

Abstract

The advantages of having Geosat Follow-On in a Geosat orbit flying simultaneously with Topex Follow-On in a Topex/Poseidon orbit are examined. The orbits are evaluated using two criteria. The first is the acute crossover angle. This angle should be at least 40 degrees in order to accurately resolve the slope of sea level at crossover locations. The second is tidal aliasing. In order to solve for tides, the largest consituents should not be aliased to a frequency lower than two cycles/year and should be at least one cycle discrete from one another and from exactly two cycles/year over the mission life. The results show that TFO and GFO in these orbits compliment each other. Both satellites have large crossover angles over a wide latitude range. In addition, the Topex orbit has good aliasing characteristics for the M2 and P1 tides for which the Geosat orbit has difficulty.

1. Introduction

Sampling even the deep ocean with satellite altimetry requires more than one satellite flying simultaneously to adequately resolve scientifically interesting ocean variations. If Geosat Follow-On (GFO) is constrained to be in the same orbit as the Geosat Exact Repeat Mission (ERM), then it is important to optimize the orbit of Topex Follow-On (TFO) in relation to the Geosat orbit. One possible orbit for TFO is the Topex/Poseidon (T/P) orbit. The Geosat ERM orbit has a 17 nodal day exact repeat period with a semimajor axis of 7158 km and an inclination of 108 degrees, while the Topex orbit has a 10 nodal day exact repeat period with a semimajor axis of 7714 km and an inclination of 66 degrees.

Two criteria that can be used to evaluate the GFO and TFO orbits are the acute crossover angle and the aliasing of tides. For this study the requirements of Parke et al. (1987) are adopted. First, the acute crossover angle should be at least 40 degrees. This allows the error in each component of the slope of sea level found from the crossover to be less than twice the error along a single track. This criterion is always violated near the turning latitude, but should not be violated elsewhere. Second, the largest amplitude tides should have aliased frequencies of at least two cycles per year and be at least one cycle discrete from one another and from exactly two cycles per year over the length of the mission.

2. Crossover Angle

The acute crossover angle , η, is the smallest angle made by crossing ground tracks and is defined as

$$\begin{aligned} \eta &= \Psi \text{ if } \Psi \leq \pi/2 \\ \eta &= \pi - \Psi \text{ if } \Psi \geq \pi/2 \end{aligned} \tag{1}$$

where Ψ is the polar crossover angle, i.e. the angle between crossing ground tracks measured on the polar side of the crossover. After Parke et al. (1987) this may be found as follows. γ is the angle between a ground track and a meridian or half of Ψ. Figure 1 illustrates the geometry. This angle is found by subtracting earth's rotational velocity vector, $\mathbf{v_E}$, from the satellite velocity vector projected on the earth's surface, $\mathbf{v_S}$. For a circular orbit, $\mathbf{v_S}$ has a magnitude, V_S, and an angle from the meridian, α, given by

$$V_S = \frac{R}{a}\left(\frac{\mu_E}{a}\right)^{1/2} \tag{2}$$

$$\sin\alpha = \text{abs}\left(\frac{\cos \mathrm{i}}{\cos\Phi}\right) \tag{3}$$

where Φ is the latitude. If V_E is the equatorial rotational velocity of the earth ($R\omega_E$), then the magnitude of $\mathbf{v_E}$ is $V_E \cos\Phi$. The polar crossover angle is then given as

$$\Psi = 2\gamma = 2\tan^{-1}\left[\text{abs}\left(\frac{\mathrm{V_S}\sin\alpha \pm \mathrm{V_E}\cos\Phi}{\mathrm{V_S}\cos\alpha}\right)\right] \tag{4}$$

where the numerator is added for retrograde orbits and subtracted for prograde orbits.

As stated before, the restriction that the acute crossover angle should not be less than 40 degrees is being adopted in order that the error in the two components of a crossover not be larger than twice the error along a single track. This is so that the two orthogonal components of the slope of sea level can be determined with comparable accuracy. Figures 2 and 3 show the acute turning angle as a function of latitude for GFO and TFO respectively. GFO (Figure 2) does well from 0 to 71 degrees latitude while TFO (Figure 3) does well from about 8 to 64 degrees latitude. This means TFO in a Topex orbit would not extend the coverage of GFO, but it would have good crossover angles over a large latitude range should GFO fail or should TFO and GFO not fly simultaneously.

3. Tidal Aliasing

Aliasing occurs when there is variability in a signal at scales finer than twice the sampling interval (Bendat and Piersol, 1971), that is the Nyquist sampling criterion is violated. Energy at these scales will be aliased to longer scales in the sampled data. Parke et al. (1987) discusses the temporal aliasing of tides. The principal alias period can be calculated from the change of tidal phase over a given repeat period. A tide with period, T, will have a phase change given by

$$\Delta\Phi_p = \frac{2\pi D}{T}\left(\frac{2\pi}{\omega_E - \dot{\Omega}}\right) \tag{5}$$

and, if the repeat period is P, the principal alias period, τ_p is

$$\tau_p = \text{abs}\left(\frac{2\pi \mathrm{P}}{\Delta\Phi_\mathrm{p}}\right) \tag{6}$$

In addition to temporal aliasing, Parke and Born (1993) discuss spatial distortion that occurs because the satellite samples the ocean as a sequence of individual tracks lain down from turning latitude to turning latitude. This means that the time between adjacent tracks and the perpendicular distance between tracks are also important. Spatial distortion due to sampling may make measured phenomena appear to satisfy the dispersion relation of other phenomena.

Table 1 gives a list of the tidal constituents considered here and their equilibrium amplitudes. This is presented because if a sampling problem exists, the importance depends on the magnitude of the tide and whether tides that are nearby in frequency have sampling problems. Small tidal constituents can be adequately estimated from nearby larger constituents if these can be resolved. Tables 2 and 3 give the aliased frequency and wavelength of all tidal constituents with equilibrium amplitude greater than 0.1 cm for the GFO and TFO orbits. According to Parke et al. there are two requirements to solve for the tides. First, the aliased frequency of the largest tides must be at least two cycles per year. Second, the alias periods of the different tidal constituents should differ by at least one cycle from each other and from exactly two cyles per year over the length of the mission. The meaning of the wavelength given in the tables is discussed in Parke and Born. A negative sign means that the apparent wave appears to be propogating to the west. A small wavelength means the sampling wavelength will appear throughout the deep water, while a large wavelength means the underlying wavelength of the tide will dominate.

Table 2 shows the tidal aliasing characteristics of GFO. There are several aliasing problems. The M2 tide is aliased to 1.15 cycles per year. The K1 tide is close to 2 cycles per year. It would require 12.5 years of GFO data to sufficiently separate the K1 tide from the twice per year signal. Finally, the P1 tide is aliased to near zero frequency. The T2 and $\pi 1$ tides are also aliased to low frequencies, but these tides have low equilibrium amplitudes and are not as important.

The tidal aliasing characteristics of TFO are shown in Table 3. The only significant tide that has an aliasing problem is the K1 tide which is close to the two cycles per year signal. It would require 9 years of data to adequately separate the K1 tide from the twice per year signal. The only other problem is the $\phi 1$ tide, but it has a low equilibrium amplitude. TFO in a Topex orbit would compliment GFO by allowing the M2 and P1 tides to be resolved. The only tide with a problem for both TFO and GFO is the K1. However, with Geosat, T/P, GFO, and TFO there should be well over 12.5 years of data available and K1 should not be a problem.

4. Conclusions

If GFO is to fly in a Geosat ERM orbit, it is important for TFO to fly in an orbit that will compliment the information obtained from GFO. In particular, it is desirable that TFO have acute crossover angles large enough to accurately resolve the two components of the slope of sea level at crossover locations and that TFO's tidal aliasing characteristics resolve tidal constituents that cannot be resolved by GFO alone.

The Topex orbit has good crossover angles over a wide range of latitudes. Although, it does not add to the area of coverage given by GFO it does provide additional coverage over a wide latitude range which will supplement the information provided by GFO and would provide good coverage should GFO fail.

The tidal aliasing characteristics of the Topex orbit would provide information on the M2 and P1 tides that is not available from GFO. One strong advantage of this satellite combination is that both satellites can operate effectively in the absence of the other.

References

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Table 1: Equilibrium Amplitude and Period for Selected Tidal Constituents (with maximum equilibrium amplitude exceeding 0.1 cm)

Equilibrium Amplitude	Period (hrs)	Symbol
Terdiurnal Tide		
0.22	8.2804008	M3
Semidiurnal Tides		
16.83	12.4206012	M2
7.83	12.0000000	S2
3.26	12.6583482	N2
2.13	11.9672348	K2
0.63	12.6260044	$\nu2$
0.47	12.1916202	L2
0.46	12.0164492	T2
0.44	12.9053745	2N2
0.41	12.6604146	-
0.41	12.8717576	$\mu2$
0.39	12.1897040	-
0.12	12.2217742	$\lambda2$
0.12	11.7545217	KJ2
0.11	12.9075223	-
Diurnal Tides		
9.83	23.9344697	K1
6.99	25.8193417	O1
3.25	24.0658902	P1
1.35	26.8683567	Q1
0.59	24.8332484	M1
0.55	23.0984768	J1
0.30	22.3060742	OO1
0.26	26.7230533	$\rho1$
0.25	23.0915993	-
0.21	26.8776683	-
0.19	24.1321400	$\pi1$
0.18	28.0062225	2Q1
0.14	23.8044765	$\phi1$
0.11	27.8483876	$\sigma1$
0.11	25.8107490	-
Long Period Tides		
2.90	327.858969	Mf
1.53	661.309205	Mm
1.35	4382.90521	Ssa
0.74	655.717998	-
0.56	219.190386	-

Table 2: GFO Alias Frequency, Wavelength, and Velocity for Selected Tidal Constituents (with maximum equilibrium amplitude exceeding 0.1 cm)

Period (hrs)	Symbol	Frequency (cpy)	Equatorial Wavelength (tracks)	Equatorial Wavelength (km)	Equatorial Velocity (cm/sec)
Terdiurnal Tide					
8.2804008	M3	8.98	3.44	524.5	14.93
Semidiurnal Tides					
12.4206012	M2	1.15	-5.16	-786.8	-2.87
12.0000000	S2	2.16	-104.25	-15905.5	-109.01
12.6583482	N2	7.01	3.30	503.6	11.19
11.9672348	K2	4.16	-38.39	-5857.8	-77.27
12.6260044	$\nu 2$	8.79	3.47	529.1	14.73
12.1916202	L2	9.32	-11.78	-1797.9	-53.09
12.0164492	T2	1.16	-732.00	-111684.9	-411.52
12.9053745	2N2	6.24	-2.43	-370.3	-7.33
12.6604146	-	6.90	3.29	502.1	10.98
12.8717576	$\mu 2$	4.47	-2.52	-383.9	-5.44
12.1897040	-	9.21	-11.91	-1817.8	-53.03
12.2217742	$\lambda 2$	10.33	10.06	1534.1	50.21
11.7545217	KJ2	4.00	7.40	1129.4	14.33
12.9075223	-	6.36	-2.42	-369.5	-7.44
Diurnal Tides					
23.9344697	K1	2.08	-76.79	-11715.7	-77.27
25.8193417	O1	3.23	-4.83	-737.3	-7.56
24.0658902	P1	0.08	291.50	44475.2	11.47
26.8683567	Q1	4.93	3.16	482.9	7.55
24.8332484	M1	10.25	10.41	1588.9	51.60
23.0984768	J1	6.08	8.19	1249.9	24.10
22.3060742	OO1	7.40	-4.29	-654.9	-15.35
26.7230533	$\rho 1$	6.71	3.32	506.2	10.76
23.0915993	-	5.97	8.13	1240.4	23.47
26.8776683	-	4.82	3.16	481.4	7.35
24.1321400	$\pi 1$	0.92	-85.78	-13088.7	-38.10
28.0062225	2Q1	8.32	-2.35	-359.0	-9.47
23.8044765	$\phi 1$	4.08	-33.92	-5176.1	-66.94
27.8483876	$\sigma 1$	6.55	-2.44	-371.7	-7.72
25.8107490	-	3.12	-4.85	-740.6	-7.33
Long Period Tides					
327.858969	Mf	5.32	-4.55	-693.7	-11.68
661.309205	Mm	8.17	9.17	1399.1	36.21
4382.90521	Ssa	2.00	-60.78	-9273.0	-58.77
655.717998	-	8.05	9.09	1387.3	35.40
219.190386	-	2.85	3.04	463.7	4.19

Table 3: TFO Alias Frequency, Wavelength, and Velocity for Selected Tidal Constituents (with maximum equilibrium amplitude exceeding 0.1 cm)

Period (hrs)	Symbol	Frequency (cpy)	Equatorial Wavelength (tracks)	Equatorial Wavelength (km)	Equatorial Velocity (cm/sec)
Terdiurnal Tide					
8.2804008	M3	9.60	-2.50	-741.1	-22.54
Semidiurnal Tides					
12.4206012	M2	5.88	3.74	1111.7	20.71
12.0000000	S2	6.22	-15.09	-4482.7	-88.34
12.6583482	N2	7.38	-2.67	-792.4	-18.52
11.9672348	K2	4.22	-19.99	-5938.6	-79.40
12.6260044	ν2	5.60	-2.77	-824.1	-14.63
12.1916202	L2	17.70	-6.27	-1862.1	-104.44
12.0164492	T2	7.22	-13.44	-3993.2	-91.35
12.9053745	2N2	16.21	2.07	615.6	31.61
12.6604146	-	7.49	-2.66	-790.5	-18.76
12.8717576	μ2	17.98	2.14	634.5	36.15
12.1897040	-	17.59	-6.31	-1872.8	-104.38
12.2217742	λ2	17.36	5.75	1707.8	93.95
11.7545217	KJ2	9.04	-17.35	-5152.5	-147.54
12.9075223	-	16.09	2.07	614.4	31.33
Diurnal Tides					
23.9344697	K1	2.11	-39.98	-11877.3	-79.40
25.8193417	O1	7.99	4.13	1226.5	31.05
24.0658902	P1	4.11	-24.24	-7200.2	-93.76
26.8683567	Q1	5.27	-2.86	-849.1	-14.17
24.8332484	M1	15.37	-7.54	-2238.8	-109.01
23.0984768	J1	11.15	-12.10	-3593.6	-126.92
22.3060742	OO1	12.21	5.20	1545.8	59.80
26.7230533	ρ1	3.49	-2.98	-885.5	-9.80
23.0915993	-	11.26	-11.97	-3554.1	-126.80
26.8776683	-	5.38	-2.85	-846.8	-14.44
24.1321400	π1	5.11	-20.25	-6015.8	-97.40
28.0062225	2Q1	18.31	2.19	649.2	37.68
23.8044765	ϕ1	0.11	-114.10	-33894.3	-11.76
27.8483876	σ1	16.75	-2.26	-670.4	-35.58
25.8107490	-	8.10	4.15	1231.2	31.61
Long Period Tides					
327.858969	Mf	10.10	4.60	1367.8	43.77
661.309205	Mm	13.26	-9.29	-2758.8	-115.88
4382.90521	Ssa	2.00	-61.55	-18284.6	-115.88
655.717998	-	13.37	-9.21	-2735.5	-115.88
219.190386	-	3.16	-3.08	-914.4	-9.15

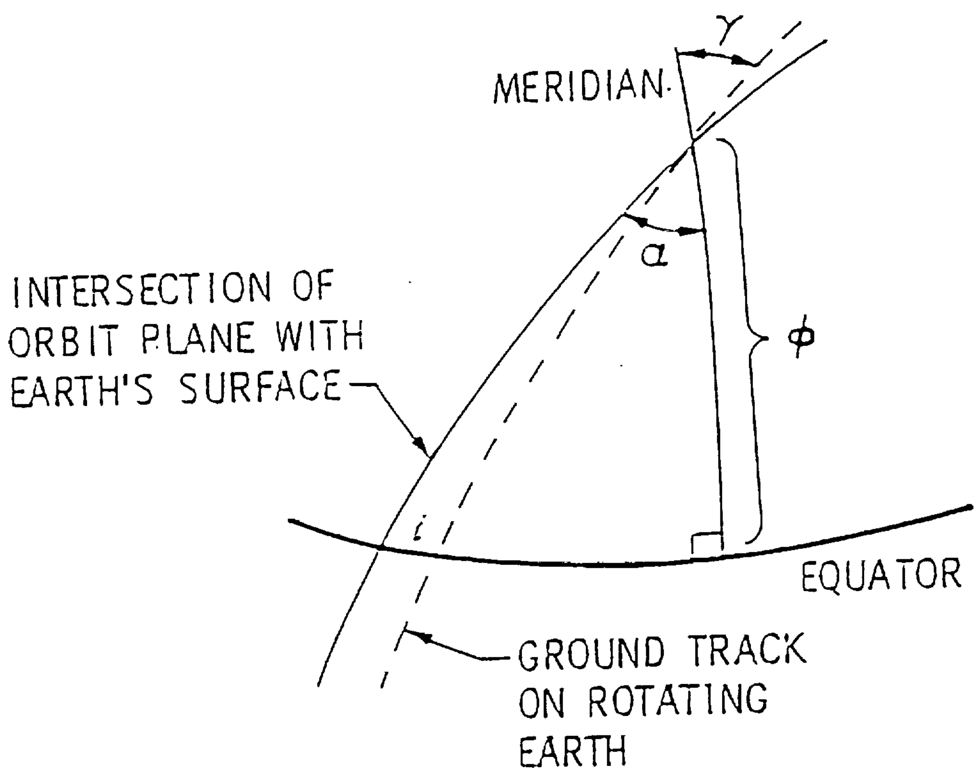

Figure 1: Ground track geometry after Parke, et al, 1987.

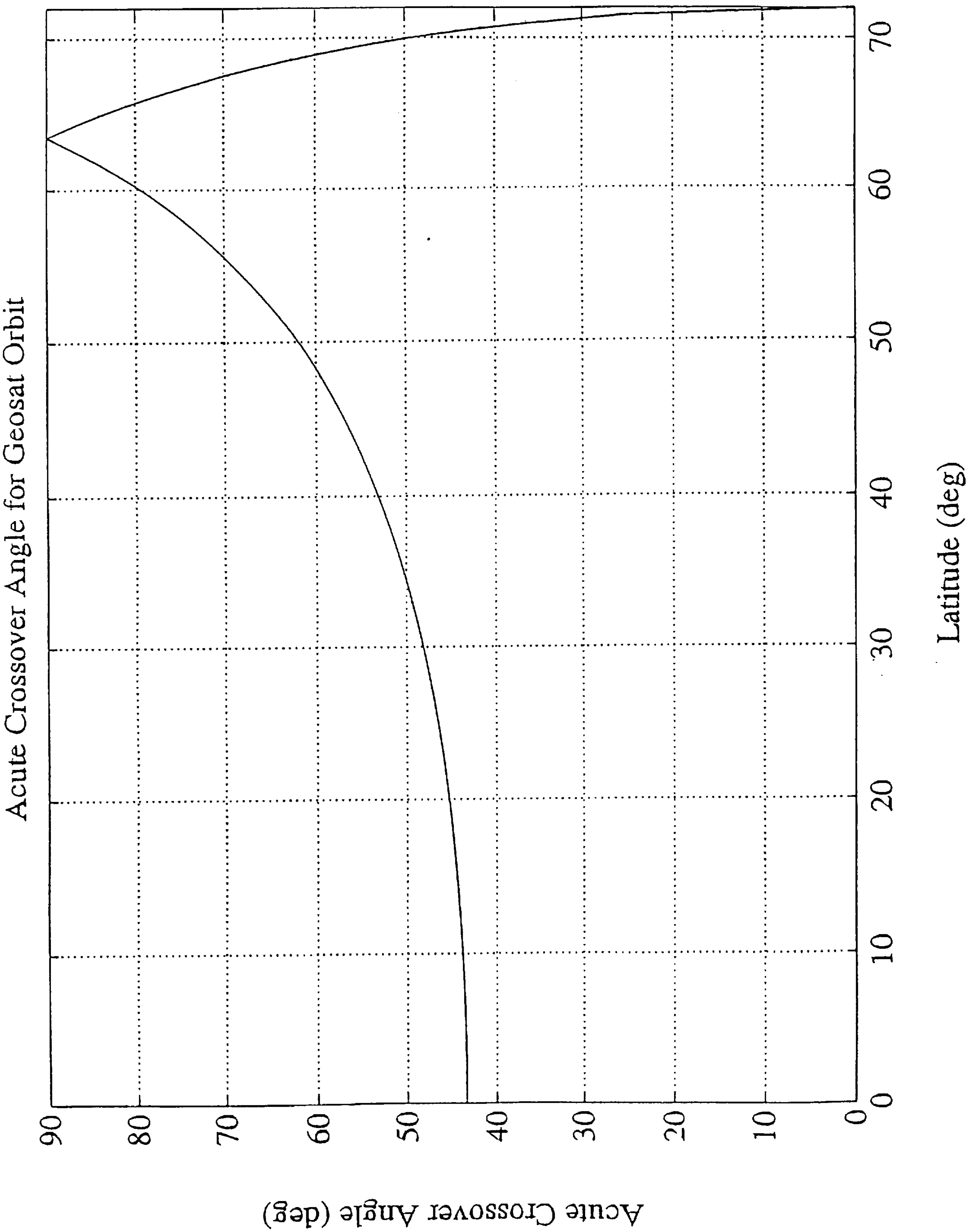

Figure 2: Acute crossover angle for GFO orbit as a function of latitude.

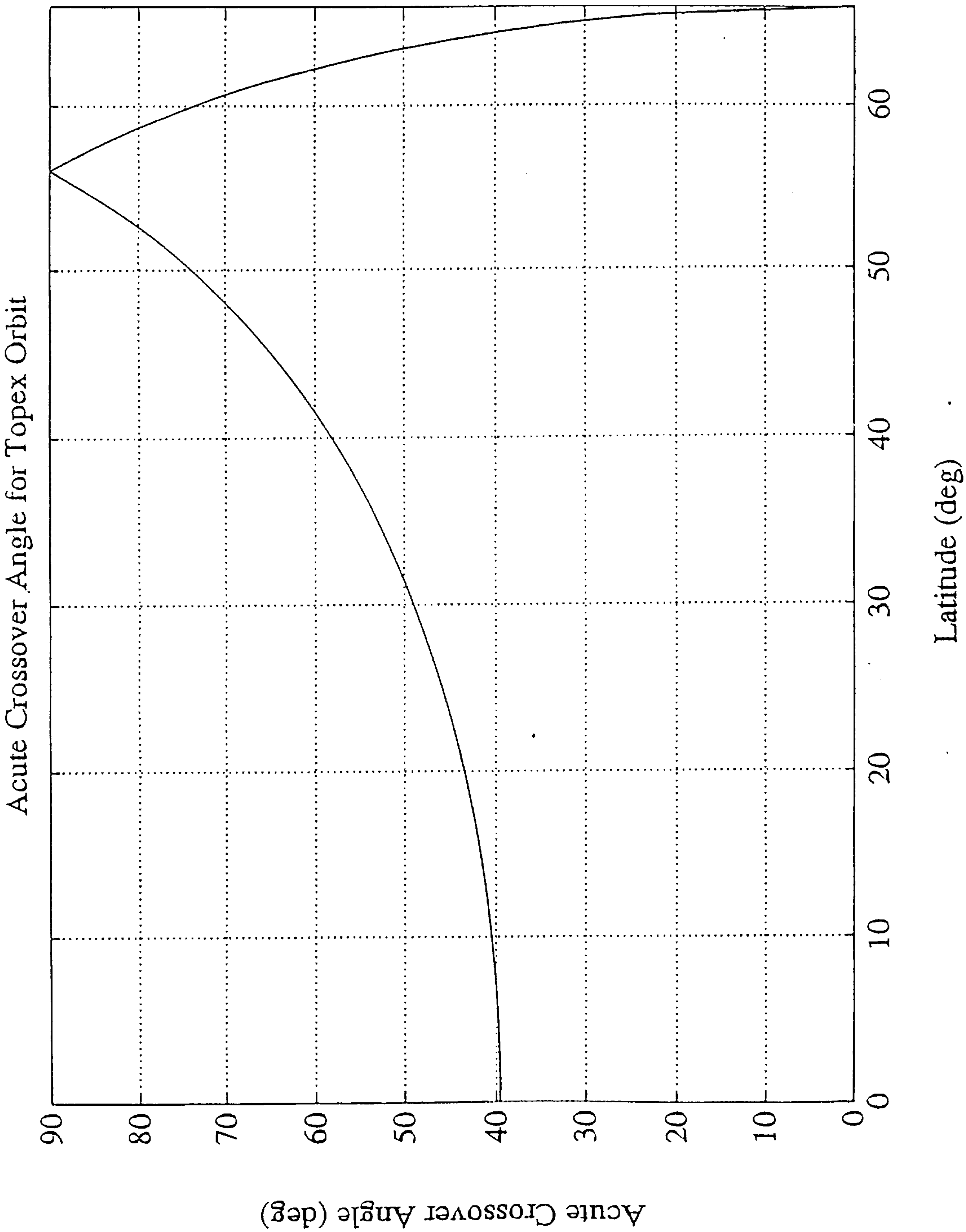

Figure 3: Same as Figure 2 except for TFO orbit.